PROBABILISTIC ANALYSIS OF REINFORCED CONCRETE FRAME

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PROBABILISTIC ANALYSIS OF REINFORCED CONCRETE FRAME

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CERTIFICATE

*This is to certify that the thesis entitled "**PROBABILISTIC ANALYSIS OF REINFORCED CONCRETE FRAME**" submitted by **Aurojyoti Prusty** to the National Institute of Technology, Rourkela for the award of the degree of **Bachelor of Technology in Civil Engineering and Master of Technology (Dual Degree) with specialization in Structural Engineering** is a bona fide record of research work carried out by him under my supervision. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.*

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LIST OF SYMBOLS

R	Response Reduction Factor
I	Importance Factor
f_c	Compressive Strength of Concrete
f_y	Yield Strength of Steel
E_c	Young’s Modulus of Concrete

E_s	Elastic Modulus of steel
f_{yh}	Yield Strength of Steel in Transverse Direction
ϵ_{cc}	Strain corresponding to Compressive strength of Concrete
f_{co}	Compressive strength of Unconfined Concrete
ϵ_{co}	Strain corresponding to Unconfined Compressive strength
ϵ_{cu}	Ultimate strain of Confined Concrete
f_s	Yield Strength of Steel
k_{fc}	Ratio of Confined to Unconfined Compressive Strength

ABSTRACT

KEYWORDS: *RC frame, pushover analysis, fiber element mesh, probabilistic analysis, probabilistic distribution, Monte-Carlo simulation, yields base shear, histogram.*

Nonlinear response of reinforced concrete structures is sensitive to the material properties of the constituents. A probabilistic analysis is required to assess the uncertainty exist in the response. In this study, a single storey single bay frame is designed using the Indian Standard code of practice for seismic loads. A computational model based on a fiber element concept is developed using Opensees platform. Parameters such as compressive strength of concrete, Young's modulus of concrete, yield strength of main steel, yield strength of transverse steel factors, geometric properties of beam and column are considered as random variable. A Monte-Carlo simulation is carried out in the computational model considering probabilistic distribution incorporating the uncertainties in materials. Pushover analyses of the computational models are carried out to obtain the probabilistic distribution of base shear and roof displacement at yield level. A histogram is plotted for the distribution of yield base shear and the coefficient of variation, which represents the uncertainty, is estimated. A best fit probability distribution curve is found out for the base shear at yield.

1

INTRODUCTION

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND AND MOTIVATION

Uncertainty is prevalent in the response of a structure by every aspect whenever there is involvement of components of large variability. In case of RCC structures, it may involve material strength, densities, member geometry, applied loads etc. So the involvement of so many parameters changes the behaviour of structural elements to a large extent. However the computation of the pattern of the behaviour requires a large number of data. The behaviour may include the maximum base shear, maximum moment resisting capacity, deflection at critical points etc. As a result, strength calculated by a designer certainly differs from the actual ones. This difference between the performances based values and real values is negotiated in the design members through safety criteria in the design codes Hence, for realistic analysis, it is necessary to look for expected values and variance of the structural response, considering random input parameters. Several methods for probabilistic structural analysis have been studied in the past years. Monte-Carlo simulation method.is the simplest way to achieve the probabilistic studies, In fact Monte-Carlo method is statically consistent and may be computationally very expensive when several degrees of freedom is involved. In this study, the structural response of reinforced concrete frame, especially the yield base shear, which is a significant parameter for the response of peak base shear versus roof displacement, depends largely on various geometric and material parameters of the associated components. Most of these parameters are of a random nature, and hence, uncertainty exists in the response of the RC members in terms of the strength and ductility. Therefore, a realistic evaluation of the behaviour of the RC structural system that is an assembly of a number of structural components requires a probabilistic approach for an appropriate treatment of uncertain structural properties. The specific objectives of the present study are as follows.

1.2 OBJECTIVES

- To study the probabilistic analysis of RC frame incorporating various uncertainties by Monte-Carlo method of simulation.
- To study the uncertainty in the base shear capacity and displacement responses at yield level of the RC frame.

1.3 METHODOLOGY

The methodology worked out to achieve the above-mentioned objectives is as follows:

- Review the existing literature in the area of probabilistic analysis.
- Validation of the modelling approach.
- Modelling of the RC frame using fiber element in Opensees platform.
- To do Monte-Carlo simulation to incorporate randomness in the variables considered.
- Non-linear static analysis of each models generated.
- Fitting of probabilistic distribution responses at yield level of frame.
  - Analysis of Coefficient of Variation of the responses

1.4 ORGANIZATION OF THESIS

Chapter 1 gives a brief introduction to the importance of the probabilistic analysis of RC frame and how the structural parameters play a big role on the behaviour of a structure. After that, the importance of Monte-Carlo simulation in the probabilistic studies and the application of it are discussed. How the simulation is incorporated to it.is also described. The need, objectives and scope of the proposed research work are identified along with the methodology that is followed to carry out the work.

Chapter 2 presents the detail description of the literature review of the previous works related to the probabilistic studies of RC related structures. This Chapter also gives the clear idea towards the research work done in this paper.

Chapter 3 presents the procedure details of the design of the RC frame using design codes, formulation of fiber element method, concrete mesh formulation, incorporation of Monte-Carlo method of simulation of taken variables.to the designed frame, sighting on the variables taken for this study and discussion on the parameters depends on it, properties of confined and unconfined concrete, detail description of pushover analysis, description of constitutive model of steel and concrete are described. Then how the non-linear analysis is carried out is thoroughly described. Finally, the procedure for the extraction of yield base shear values is given and all the graphs are plotted. In the next phase, the procedure for the histogram is given and how to fit the best probability distribution is elaborated

Chapter 4 is the last part of this work and mainly focuses on the results and conclusion part. The whole work is summarized at a glance and the final conclusion is given.

2

LITERETURE REVIEW

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

As the present study deals with the probabilistic analysis of RC frame, a literature review has been conducted on previous studies on probabilistic analysis of RC frames. This Chapter presents various literatures in this area.

2.2 PREVIOUS RESEARCH WORKS ON PROBABILISTIC ANALYSIS OF STRUCTURE.

Val *et al*. (1997) implemented the probabilistic method for reliability evaluation in the context of nonlinear analysis of RC plane frame structures including both structural and probabilistic models. The effect of correlation of the material strengths within the structure on the reliability index was examined and the correlation at member level was found to predominate compared with that within individual members. For the structural type, the uncertain parameters of the structural model with the major influence on the reliability index were identified as the basic random variables via sensitivity analysis. The model uncertainty associated with the adopted structural model was considered. A method was proposed, permitting estimation of the influence of the model uncertainty on the reliability index and using the central safety factor and the value of the reliability index obtained with the model uncertainty excluded as initial data.

Araujo (2001) has done work related to the probabilistic analysis of RC columns. In this case the concrete properties are described as homogeneous Gaussian random fields. Column cross-section dimension, yield stress of cross-section and reinforcement position and load in axial direction were taken as variables. The Monte-Carlo simulation was utilized to get almost expected results and standard deviation of failure of column. It is shown that in order to obtain realistic safety analysis it is required to consider spatial variability. Procedures which consider concrete properties as single random variables are unsuitable for safety. Furthermore, the correlation length has a significant effect on reliability. This study has shown that reliability of reinforced concrete columns depends on several parameters related to the design method as well as to the variability of basic variables. The main parameters of the design method are the first order eccentricity, slenderness ratio and the design value of the applied load. Increasing any of these parameters implicates in an increase of the steel reinforcement ratio and this has a favourable effect on reliability

Soares *et al.* (2001) formulated to compute the reliability of reinforced concrete structures in which structural and geometrical parameters are taken into account. This model is able to describe the mechanical behaviour of concrete at the failure stage which due to various parameters involved in concrete. The failure surface is obtained by fitting the internal force ultimate state of the structure using quadratic polynomial. The structural reliability index is estimated by some algorithm. A parametric numerical analysis of columns and frames is presented for practical application, where the partial safety factors proposed by international codes of practice are associated with reliability indexes.

Lee and Mosalam (2004) designed computational tool for a probabilistic evaluation for RC structural model is developed using stochastic fiber element formulation. Monte Carlo method of simulation is incorporated in the structure to compute the probabilistic analysis of RC structures The stochastic fiber element model is developed by combining the conventional fiber element formulation and the midpoint method for random field representation A probabilistic strength analysis of a RC column subjected to combined axial load and lateral load is conducted in terms of the axial load and bending moment interaction. Compressive strength of concrete, yield strength of steel, strain at maximum stress are considered for the evaluation. They found that compressive strength of concrete controls the variation of the column strength whereas the yield strength of concrete controls the tension failure region. The importance of spatial variability is also discussed

Towashiraporn (2004) suggested an alternative methodology for carrying out the structural simulation. The use of Response Surface Methodology in connection with the Monte Carlo simulations abridges the process of fragility computation. The usefulness of the response surface metamodels becomes more apparent for promptly deriving fragility curves for buildings in a portfolio. After metamodels applicable for building inventory in a geographical expanse are developed, they can be used for analysis of any portfolio of interest, located within the same region. The ability for quick estimation of fragility relation for a discrete building in a target portfolio was a noteworthy step toward more accurate seismic loss estimation.

Bakhshi and Asadi (2012) have done research on the probabilistic evaluation of seismic design parameters on RC frame. General consideration parameters like PGA, importance factor, inherent over strength factor, global ductility capacity(R) are considered as the uncertain variable which affects the seismic performance of structure. As the main characteristic of design of structures under seismic excitation is probabilistic rather than deterministic, the attempted to determine whether the damage decreases when there is some variation in the parameters. Fragility curves are developed to determine these parameters. These diagrams used to improve the performance of the structure as well as the effect of uncertainty in the design parameters. They found that increasing the global ductility capacity (R), the probability of damage exceedance is decreased; however, an increase in importance factor (*I*) for hospital buildings versus office buildings, cannot guarantee a decrease in the probability of damage exceedance. The PGA randomness results reveal that considering PGA uncertainty does not mean that the probability of damage exceedance will be increased in general cases.

Devandiran *et al.* (2013) evaluated the uncertainties in the capacity of the building by taking cross sectional dimension of beam and columns, density and compressive strength of concrete, yield strength and elastic modulus of steel and live load as random variables. From nonlinear static and dynamic analysis they tried to determine the statistical properties and suitable distribution parameters function for spectral displacement.by using Monte-Carlo simulation. Then suitability of different probability distribution is like normal, lognormal, Weibull are examined for the goodness of fit and it is found that lognormal fits the best for the given number of data.

Balasubramanian *et al.* (2013) described a simple procedure which assemble collectively an improved storey shear modelling, Dynamic Analysis (incremental) and Monte-Carlo Simulation method to carryout analysis which gives the danger, risk associated with development of fragility curves for Unreinforced Brick Masonry buildings. The procedure is elaborated by fragility curves development of a single storey Brick Masonry building (Not reinforced) for which experiment under lateral load is available in the literature. In this study, uncertainties both in mechanical properties of masonry and uncertainties in the nature of ground motion are taken. The significance of the procedure elaborated is that, it adjusts a new method of damage grade classification which is based on structural performance characteristics instead of fixed limiting values.

2.3 SUMMARY

From the above discussion, it is found that only few studies have been done on the area of probabilistic analysis. The present study is focussed on the modelling of RC frame for nonlinear static pushover analysis and a probabilistic analysis to obtain the uncertainty in the responses.

3

PUSHOVER ANALYSIS INCORPORATING UNCERTAINTIES

CHAPTER 3

PUSHOVER ANALYSIS INCORPORATING UNCERTAINTIES

3.1 INTRODUCTION

This Chapter discusses about the methodology, case study frame, uncertainty modelling of material and geometric properties, Monte-Carlo simulation, pushover analysis and the estimation of probabilistic distribution of the nonlinear responses of the RC frame.

3.2 METHODOLOGY

The complete methodology followed for probabilistic analysis in this study is explained in the flow chart given in Fig.1.

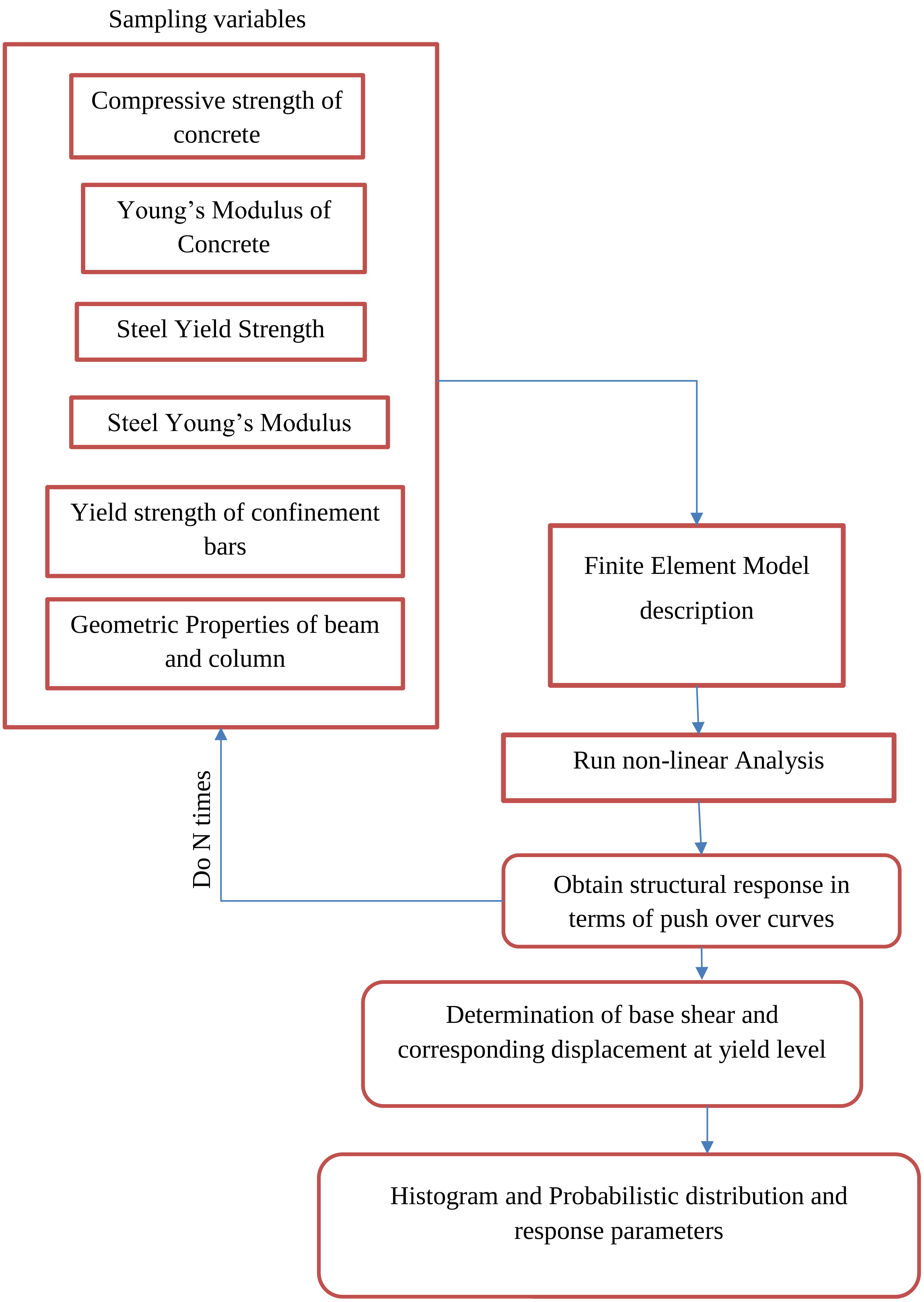

Fig.1 Flowchart describing complete methodology

3.3 CASE STUDY FRAME

An RC frame with height 4m and span 8m is designed according to the design guidelines given by IS-456. The assumed beam and column dimension is 350 x 550 and 350 x 500 respectively. The details of the manual design of single bay and single storey frame are given in Table 1. The dead weight is calculated and a live load of 1.5kN/m^2 is considered. The frame is designed for the gravity loads (vertical loads) as per IS1893. The Dimension details of the frame are given in the Table.2. Fig.3 to Fig.6 represents the beam and column sections respectively.

Table 1: Design parameters taken in the design of frame

Properties	**Values**
Compressive strength of concrete, f_c	30MPa
Yield stress of longitudinal steel, f_y	415MPa
Elastic modulus of concrete, E_c	$5000\times\sqrt{fc}$
Elastic modulus of steel, *Es*	200GPa
Yield stress of transverse steel, f_{yh}	415MPa

Table 2: Design details of beam and column (Geometry)

Description	**Beam**	**Column**
Depth(mm)	550	500
Width(mm)	350	350
Clear cover(mm)	25	30

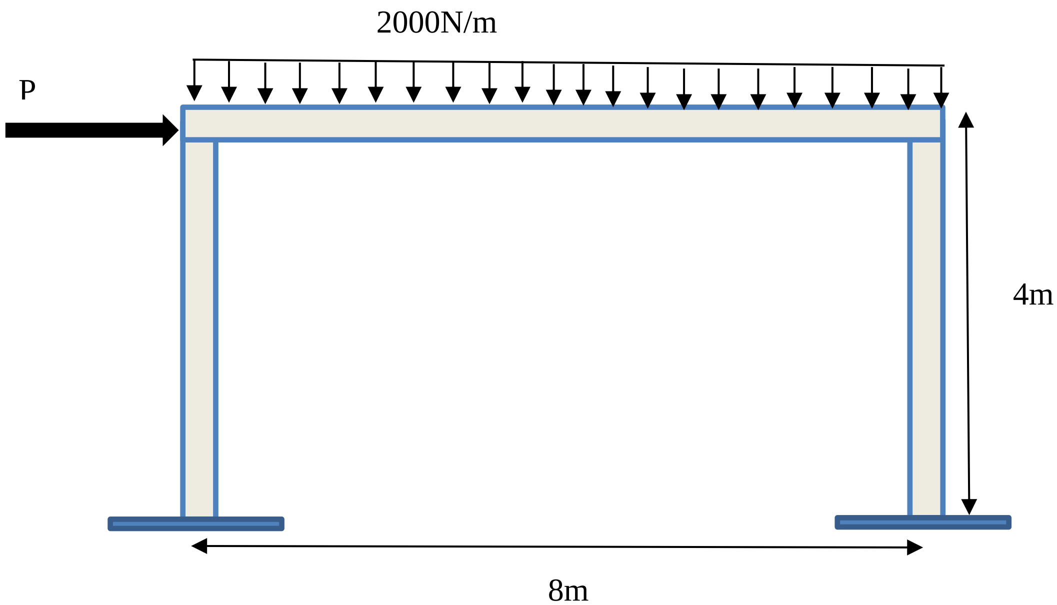

Fig.2: Loading and geometric details of case study frame

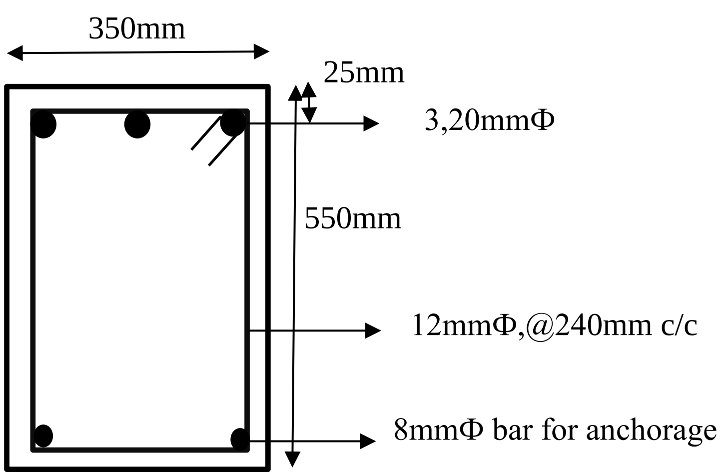

Fig 3 Cross section and reinforcement detailing of the beam

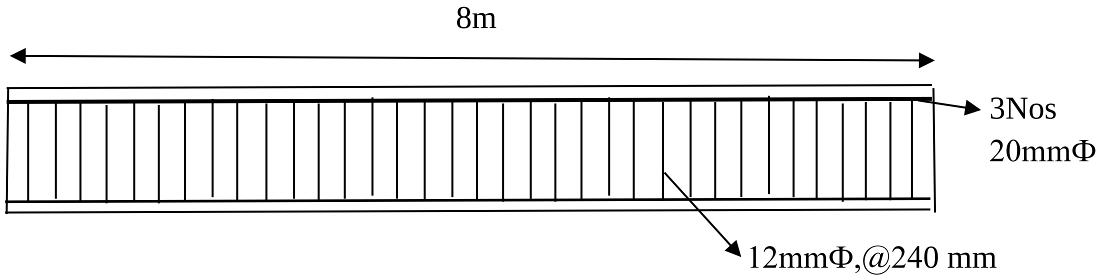

Fig.4 Beam detailing

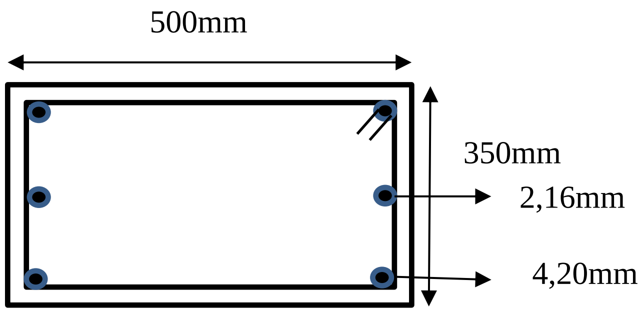

Fig.5 Cross section and reinforcement detailing of columns

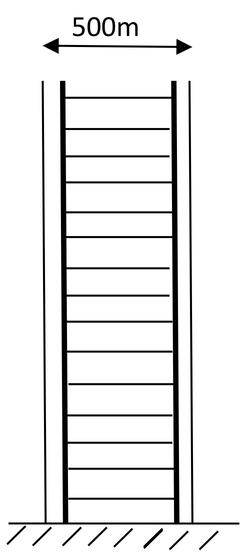

Fig.6 Sectional view of column

3.4 MODELLING FOR NONLINEAR STATIC PUSHOVER ANALYSIS

3.4.1 Fiber Based Element

According to Lee and Mosalam (2004), non-linear properties of material mainly analyzed by either lumped or distributed plasticity model. In the lumped plasticity method, two zero-length nonlinear rotational spring elements attached to elastic elements, which form a member. Here moment-rotation relationship of the spring element will capture the non-linear properties of the element. The distributed plasticity approach is useful when one require material non-linearity anywhere in the designated element. The present study uses distributed plasticity approach using non-linear beam element formulation.

3.4.2 Constitutive Models

Nonlinear beam column element uses fiber element with uniaxial stress strain relationship. The core concrete is modelled as confined concrete model proposed by Mander *et al*. (1988) and cover concrete is modelled as unconfined. Fig.7 shows the stress strain relationship for both confined and unconfined concrete as per Mander *et al.* (1988). The parameters involved in the compressive strength f_{cc}, corresponding strain ϵ_{cc}, ultimate strain of confined concrete ϵ_{cu}, compressive strength of unconfined concrete f_{co} and the strain ϵ_{co}. Tension regime is defined by f_t and ultimate strain ϵ_{tu} It is assumed that E_c is same for both tension and compressive regime. The behavior of the ascending branch of the model can be expressed as

$$fc = fo[\frac{2\epsilon}{\epsilon o} - \left(\frac{\epsilon}{\epsilon 0}\right)^2] \tag{3.3}$$

This equation is applicable only up to the peak strength and beyond that the stress-strain curve is assumed linear. For confined concrete the residual stress is assumed as $0.2f_{cc}$ and for unconfined concrete, it is assumed as zero. All the parameters for confined concrete are calculated from Mander's model (Mander *et al*.1988). Fig.8 represents the Steel fiber in the in the model formulation as proposed by Giuffre *et al.* (1973) also known as Menegoto-Pinto Model

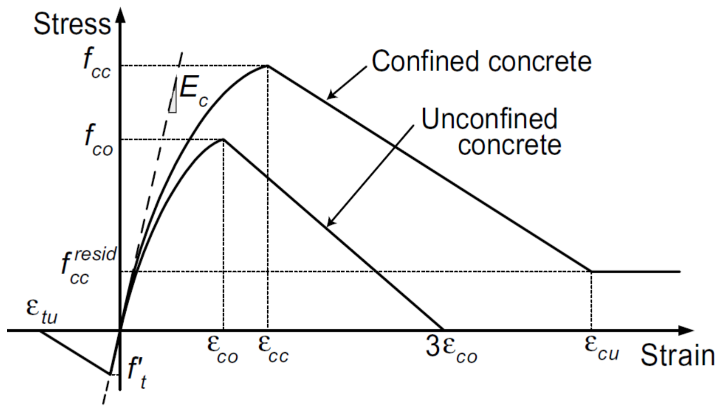

Fig.7 Concrete constitutive models (Lee and Mosalam, 2004)

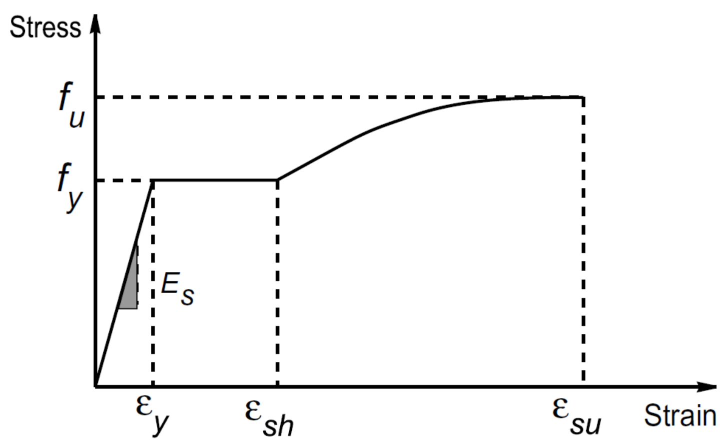

Fig.8: Reinforcing steel constitutive model (Lee and Mosalam, 2004)

3.5 PUSHOVER ANALYSIS

The present study considers only the uncertainty due to materials and geometry. A pushover analysis in which the structure is acted upon by vertical loading (gravity load) and a gradually increasing displacement controlled lateral load. When the structure is pushed beyond certain limit of deformation it undergoes a non-linear behaviour. The nonlinear behaviour is largely depends on various material and geometric factors which in turn affects the ultimate response with respect to the maximum base shear that the structure can withstand.

3.6 UNCERTAINTY IN MATERIAL AND GEOMTRIC PARAMETERS

A Monte-Carlo simulation is used in the present study where random instances of all the parameters involved are sampled and the computational model is developed for each instances. The responses from each instances of computational model are monitored to represent it probabilistically. This procedure is popularly known as Monte Carlo simulation (Rubinstein 1981).

Each random variable is assumed to follow particular probabilistic distribution, with a mean and a coefficient of variation. From the general point of view, the compressive strength of concrete is largely dependent on many parameters which are beyond control which affects the response of structure. The elastic modulus of concrete is also a function of compressive strength of concrete which is given as $5000\sqrt{fc}$ in MPa. The COV (Coefficient of variation) is taken as 0.13 and mean as 38.0 MPa (Val et.al., 1997). The assumed variance for strength of steel is 0.08 and mean as 461MPa. Statistical details of all variables are given in Table.3. The probability distributions of each random variables, compressive strength of concrete, yield strength of steel, young's modulus of concrete, depth of column, width of column, width of beam, depth of beam are displayed in Figs. 9 to 15. The yield strength of transverse reinforcement also considered as the random variable in this study.

Ratio of confined to unconfined concrete strength (k_{fc}) is a function of a number of variables which is given by

$$k_{fc} = \left(1 + 3.7\left(\frac{0.5k_e \times \rho_z \times f_{yh}}{f'_{co}}\right)\right) \tag{3.5}$$

Where $\rho_z = \rho_x + \rho_y$

f'_{co}= Unconfined compressive strength

k_e=Effective stiffness coefficient, 0.75 for rectangular section

f_{yh}=Compressive strength in transverse direction

$$\rho_x = \frac{Area\ of\ stirrup\ legs(x-direction)}{Spacing \times cover\ width} \tag{3.6}$$

$$\rho_y = \frac{Area\ of\ stirrup\ legs(y-direction)}{Spacing \times cover\ depth} \tag{3.7}$$

3.7 UNCERTAINTY IN NONLINEAR RESPONSES

The nonlinear responses of the computational models developed through Monte-Carlo simulation (10000 samples) is found out using pushover analysis in Opensees. Pushover curves, displacement along X-axis and the base shear in Y-axis are plotted. As expected, the uncertainty in the pushover curves of the frame is present. Base shear at the yield level is varies randomly from approximately 80kN to 135kN. The displacement at yield level it is varying from approximately 0.03m to 0.06m. In order to study the uncertainty in the base shear, the base shear at the yield level is found out for each pushover curve. The base shear at yield level is taken as the base shear at which the slope of the curve is less than or equal to 5% of the initial slope. Best curve is fitted using paul castro's "fitmethis" Matlab function.

Similarly, the displacement corresponding to base shear at yield is monitored and a histogram for displacement at yield is also found out and plotted. The histogram is more like a discrete distribution rather than a continuous one. As the pushover analysis is a displacement controlled loading procedure where the displacements are applied in constant increments, it is found that the yield base shear mainly occurs at these discrete values of yield displacements. To explain this, a plot showing the correlation between the base shear and displacement at yield is plotted. In other words the yield displacement varies from 0.035 to 0.06 with a mean and standard deviation of 0.0472 and 0.0043 respectively. The C.O.V being 10.97% which is less than compared to that of base shear.

The C.O.V of the Base shear at yield and corresponding displacement is only slightly less than the maximum C.O.V of the input parameters

This C.O.V values of base shear and displacement capacity can be used to calculate the margin of safety, probability of failure or reliability of the frame or in general for any RC frame.

3.8 SUMMARY

In this chapter, detail methodology of the present study, details of the case study frame is discussed. Uncertainty modelling is carried out using Monte-Carlo simulations are incorporating material and geometric properties. Pushover analysis is carried out for base shear at yield level and corresponding displacement. Probabilistic distribution of the nonlinear responses for the RC frame.is obtained and the significance of probabilistic parameters are briefly discussed.

4

SUMMARY AND CONCLUSIONS

CHAPTER 4

SUMMARY AND CONCLUSIONS

4.1 SUMMARY

The main objective of the present study is to model an RC frame for nonlinear analysis and further conduct a probabilistic analysis of RC framed structured incorporating possible uncertainties. For that purpose, a single bay and single storey RC frame is designed using Indian standard practice. The RC beams and columns are modelled using fiber based nonlinear beam column element in Opensees. Monte-Carlo simulations are carried out to develop computational models incorporating uncertainties in variables such as compressive strength, yield strength of main steel and transverse steel, modulus of elasticity of concrete, dimensions of beams and columns. Displacement controlled Nonlinear static pushover analysis is carried out to obtain the structural response in terms of base shear and corresponding roof displacement. The probabilistic distributions of responses such as base shear and displacement at yield level is carried out and a best fit probability distribution is found out. Conclusions obtained from this study, limitation of the present work and future scope is presented in this chapter.

4.2 LIMITATION OF THE PRESENT STUDY AND SCOPE FOR FUTURE WORK

- Present study only involves the material and geometrical uncertainty. Uncertainty in the loading is not considered.
- A sensitivity study to include RC frames with different geometries may be conducted for more generalised conclusions.
- Present study only limited to RC moment resisting frame.

REFERENCES

REFERENCES

1. P. Devandiran, P. Kamatchi, K. Balaji Rao, K. Ravisankar, Nagesh R. Iyer (2013), "Probabilistic analysis of spectral displacement by NSA and NDA", Earthquakes and Structures, Vol. 5, pp 439-459
2. Balasubramanian S.R, Balaji Rao K, Meher Prasad A, Rupen Goswami, and Anup M.B(2014), "A methodology for development of seismic fragility curves for URBM buildings" Earthquakes and Structures, *Vol. 6, No. 6 (2014) 611-625*
3. Gianvittorio Rizzno and Immacolata Tolone (2009), "Seismic Assessment of Existing RC Frames", *Journal of Structural Engineering,* Vol 135, No 7, July 1, 2009"
4. Dan M Frangopol, Yutuka Ide, Enrico Spacone, Ichiro Iwaki (1996), "A new look at reliability of reinforced concrete columns" Structural Safety Vol 18 No 2/3, pp.123-150
5. S.Ali Mirza (1996), "Reliability-Based Design Of reinforced concrete columns", Structural Safety Vol 18 No 2/3, pp.179-184
6. Jose Milton de Araujo (2001), "Probabilistic analysis of reinforced concrete columns", Advance in Engineering Software 32 (2001) 871-879
7. C.Q.Li(1995), "Failure Probability of reinforced concrete columns under stochastic loads", Engineering Structures, Vol 17, No 6, pp. 419-424
8. R.C Sores, A. Mohamed, W.S Venturini, M. Lemaire,(2002) " Reliability analysis of non-linear concrete frames using the response surface method" Reliability Engineering and System Safety 75(2002) 1-16
9. Tae-Hyung Lee and Khalid M. Mosalam (2004), "Probabilistic fiber element modeling of reinforced concrete structure" Computers and Structures 82 (2004) 2285-2299
10. Damitri Val, Fiodor Bljuger, David Yankelevsky (1997), "Reliability evaluation in nonlinear analysis of reinforced concrete structures", Structural Safety Vol 19 No 2, pp.203-217
11. A. Bakhshi, P.Asadi (2012) " Probabilistic evaluation of seismic design parameters of RC frames based on fragility curves", Scientia Iranica A(2013) 20(2) 231-241
12. Sayan Gupta and C.S Manohar (2006), "Reliability analysis of randomly vibrating structure with parameter uncertainties", Journal of Sound and Vibration 297 (2006) 1000-1024
13. Daniel Celarac, Paolo Ricci, Matjaz Dolsek (2012), "The sensitivity of seismic response parameters to the uncertain modelling variables of masonry-infilled reinforced concrete frames", Engineering Structures 35(2012) 165-177

14. Filip C. Filippou, Angelo D'Ambrisi, Ahmad Issa (1992), "Nonlinear Static and Dynamic Analysis of Reinforced Concrete Subassemblages", Earthquake Engineering Research Center, College of Engineering, University of California, Berkeley.
15. Gianvittorio Rizzano, Immacolata Tolone (2009), "Seismic Assessment of Existing RC Frames Probabilistic Approach", Journal of Structural Engineering, vol 135, pp 836-852.
16. Rohit Bansal (2011) "Pushover Analysis of Reinforced Concrete Frame", M.tech thesis, Thapar University
17. R. Hasan, L. Xu, D.E. Grierson (2002), "Push-over analysis for performance-based seismic design", Computers and Structures, vol. 80, pp.2483–2493.
18. G.G. Deierlein, S-H. Hsieh, Y-J. Shen and J.F. Abel (1991) "Nonlinear Analysis of Steel Frames with Semi-rigid Connections Using the Capacity Spectrum Method", Technical Report by National Center For Earthquake Engineering Research
19. http://www.mathworks.com/matlabcentral/fileexchange/40167-fitmethis